Renewable and Sustainable Energy Reviews 18 (2013) 508–518

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Climate change adaptation on the Qinghai–Tibetan Plateau: The importance of solar energy utilization for rural household

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ARTICLE INFO

Article history:
Received 23 March 2012
Received in revised form
23 October 2012
Accepted 27 October 2012
Available online 23 November 2012

Keywords:
Solar energy
Climate adaptation
The Qinghai–Tibetan Plateau (QTP)
Rural household

ABSTRACT

Solar energy is increasing essentially to fortify energy security and mitigate CO_2 emission. Although solar energy utilization on the Qinghai–Tibetan Plateau (QTP) contributes little to the energy conservation and reduction of CO_2 emission at present, it plays an important environmental role throughout Asia. Based on the solar energy applications mainly centralized on the solar cooker, the solar water heater, the solar greenhouse, and the photovoltaic devices in rural household, we analyze the sensitivity of climate change on the QTP, the potential capacity of solar resource on the QTP, the effect of solar energy utilization on CO_2 abatement, the growth demand of solar energy on the QTP, and the roadmap of solar energy development on the QTP. From different scales, we summarize the adaptation instruments related to solar energy exploitation. Finally, the closely linkage technology, cost, knowledge training with supporting policies related to solar energy have been emphasized in this paper.

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1. Introduction

The Third Assessment Report of the IPCC confirmed that the Earth's climate is changing as a result of human activities, particularly from energy use, and that further change is inevitable. Under a series of climate change impacts, adaptation plans need to be systematically considered by decision maker [1]. Due to the closely relationship between energy consumption and climate change related to the emission of greenhouse gases, global climate change induced by the emission of greenhouse gases may pose challenges to energy security. The importance of

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1364-0321/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.rser.2012.10.037

effectively responding to climate change and actively supporting renewable energy development is clear [2]. It can therefore be argued that renewable energy systems offer diversification, low carbon energy in energy supply, thus strengthening energy security and adaptive capacity of climate change by broadening national or regional energy generation portfolios. For this reason, a number of studies were undertaken for examining adaptation strategies of climate change in renewable energy sectors around the world. For instance, Venema and Clsse argued that well-designed decentralized renewable energy projects are both a mitigating and adaptive response to climate change [3]. Roy et al. investigated the impacts of climate change on the hydrological regimes of Québec's developed watersheds in order to elaborate adequate adaptation strategies over the upcoming decades. They found that adaptation measures could lead to an increase of up to 15% in hydroelectric generation, whereas without adaptation of the operating rules, and despite the increase in water availability, output could be reduced by 14% [4]. In recent study, Arent et al. present a brief summary of status, recent progress, some technological highlights for renewable energy technologies (RETs) to meet a greater share of the global energy requirements and lower GHG emission. From mitigating and adaptation future climate change perspective, they suggested that RETs must be viewed as part of broader portfolio of technologies and actions-decarbonization of energy broadly [5]. From international organization perspective, the EU is developing a strategy for adapting to the impacts of climate change that can no longer be prevented. Distinguished initiative, taken to adapt climate change, includes mandating increased use of renewable energy resources. For the purpose of the present research, the Africa Enterprise Challenge Fund (AECF) (2011) has launched a new special funding window, Renewable Energy and Adaptation to Climate Change Technologies (REACT), to catalyze private sector investment and innovation in low cost, clean energy and climate change technologies [6]. Clearly, the supporting literature to date has focused on the adaptation climate change-renewable energy connection.

Although solar energy still contributes a small portion to our energy needs, a mass shift to renewable sources of power is tantamount to a healthy future. Solar energy will no doubt play a major role in that transition. Therefore, the awareness by scientists and policy-makers of the relationship between solar energy and environmental effect increased in the late 1990s as global concern for climate change. Many investigators have tended to question the effect of solar energy on CO_2 abatement and environmental protection, where they agree it has occurred, to cast their analysis in terms of different scales and cases [7–14]. Drennen et al. have emphasized technological and policy solutions under context of climate change. Suggested sustained R&D programmes for improvements in panel and other system efficiencies involve ensuring a market for photovoltaic, providing PV manufactures with opportunities [15]. Additionally, it should be noted that more and more researchers have paid attention to household-based energy use, in particular, to the rural households, an escalating interest has been emerging for the extensive analysis of rural energy issues [16–25], because more than 2 billion rural residents in developing countries currently lack reliable electricity service, indicating a significant livelihoods thread if the problem is not addressed [16]. The Millennium Goads described by the 2002 World Summit on Sustainable Development include the recognition of this problem [16], and residential energy use represents about 35% of global energy use and it therefore plays a key role in global energy-related environmental problems such as climate change and resource scarcity [26–28]. In the past decades, many researchers have made great efforts in investigating the relationship between mitigation, adaptation of climate change and renewable energy. However, we have not found any analysis, which highlights the importance of solar energy utilization in strategically adaptation of climate change, especially the closely linkage solar energy development with adaptation of climate change. This paper addresses this question.

This paper first introduces the research methods; then analyzes the important role of solar energy utilization for rural household in adaptation of climate change; and summaries adaptation actions and barriers related to solar energy at different scales; afterwards, we propose possible strategic solutions for sustainable solar energy development for rural household on the Qinghai–Tibetan Plateau (QTP).

2. Methods

2.1. Study area

With a mean elevation of above 4000 m, the Qinghai–Tibetan Plateau, known as the "roof of the world" and "the third pole", lies in the southwest of China, covering the whole of the Tibet autonomous region, most of Qinghai province, west Sichuan province, northwest Yunnan province, south Gansu province, and southwest Xinjiang Uygur autonomous region with an area of 2.57 million km^2 [29]. The region has a typical plateau continental climate, namely a heat low, precipitation few, and evaporation quick comprises the distinguished features on the QTP [30]. Alpine cold meadow, alpine cold steppe, alpine cold swamp, alpine cold shrub and alpine desert ecosystems are the main types of vegetation cover on the plateau [30,31]. Total population on the QTP has increased from 19.92 million in 2000 to 22.83 million 2010 [32,33]. Corresponding to the number of household has increased from 4.70 million in 2000 to 5.86 million in 2010. Household sizes on the QTP have decreased since 1985; however, household sizes on the QTP are larger than the national average all the time [32–34].

2.2. Data source

2.2.1. Climate data

Temperature data: Ninety-one meteorological stations datasets from 1961 to 2010 were provided for the QTP by the Information Center of Chinese Weather Bureau.

Radiation data: Ninety-nine weather stations from "Annual Surface Solar Radiation Dataset over China" during 1995–2010 were provided by the Information Center of Chinese Weather Bureau. Of which, only 11 weather stations of solar radiation is available for the QTP.

Sunshine data: Seven-hundred and fifty-six weather stations from "China Dataset of Annual Terrestrial Surface Climate" for the period of 1995–2010 were provided by the Information Center of Chinese Weather Bureau. Of which, 99 weather stations of sunshine hours is available for the QTP.

2.2.2. Social economic data

Population and household data: The population and household data mainly comes from China County Statistical Yearbook [32,33]; and China Statistical Yearbook [34] published by China Statistics Press.

Data of rural solar energy: Total scale data of solar energy exploitation mainly comes from "Summary of Rural Renewable Energy of China" for the period of 2000–2010 provided by Science and Education Division, the Ministry of Agriculture of the People's Republic of China, and literatures [35,36]. The structural data of

solar energy utilization in rural energy consumption comes from the literature [36].

2.2.3. CO_2 emission data

Solar-related CO_2 emission data on the QTP is estimated based on literatures and research results conducted by Krauter and Rüther [8], Zou et al. [35], Sivaraman and Keoleian [10] etc.

2.3. Spatial interpolation by regularized spline function

The approach to topographic analysis based on interpolation by completely regularized spline has been applied to many fields in recent year, and the interpolation by regularized spline can directly input into various modes of landscape processes influenced by topography. As the few observation stations of solar radiation on the QTP (just 11 observed stations on the surface of QTP provided by Chinese Weather Bureau), it is not easy to gain the spatial data of radiation in this area. In this paper, we use the completely regularized spline function to interpolate for solar radiation, sunshine hours missing in certain areas.

2.4. Multiple linear functions

We use multiple linear functions to fit the causal relationship between the abatement of solar-related CO_2 emission (dependent variable) and the scales of solar cooker, solar water heater, solar greenhouse, solar PV systems exploration (independent variables) for the period of 2000–2010, respectively. Applied SPSS software was used to perform the necessary calculation.

3. Results and discussion

3.1. Particularly sensitive to climate change on the QTP

Climate change is one of the main challenges faced by mankind in this century. There is general agreement that the QTP is very sensitive to climatic changes due to this delicate energy balance and the strong monsoon influence [30,37–39]. By using 91 weather stations distributed on the QTP during 1960–2010, we find that strong increases can be observed in recent 50 years, the increasing rates per decade from 0.33 °C in the 1980s, to 0.12 °C in the 1990s, to 0.35 °C in the 2000s, and to 0.65 °C in the 2010s respectively, the mean annual warming rate reached by 0.029 °C/year over the past five decades (see Fig. 1). Other scientists have produced convincing evidence that warming trend is significant on the QTP. As Yao et al.'s study, the amplitude of climate change in the QTP was obviously larger than that in low-altitude regions [40]. They revealed that the temperature in over 3500 m regions of the QTP have been increasing at a rate of 0.025 °C/year in recent 30 year, but almost no change has taken place in the regions below 500 m. In the same year, Liu and Chen reported warming rates of 0.016 °C/year for annual means but 0.032 °C/year for winter means based on 97 stations distributed over the entire QTP during 1955–1996 [41]. Similar results were also presented by Du et al. [42], Baker and Moseley [43], Du et al. estimated that annual warming trend of 0.02 °C/year in summer but 0.13 °C/year in winter for Qinghai and Tibet, 1978–1999, and Baker and Moseley reported that warming is occurring at the southeastern extreme of the QTP.

3.2. Potential capacity of solar energy resource on the QTP

According to the data of Chinese Weather Bureau (CWB) and literatures [31,44–46], generally the solar energy resource is abundant in China with daily average radiation of 4 kW h/m^2/day, but is greatly diverse in various areas [45]. In particular, areas on the QTP receive the largest amounts of solar radiation in all of China for its

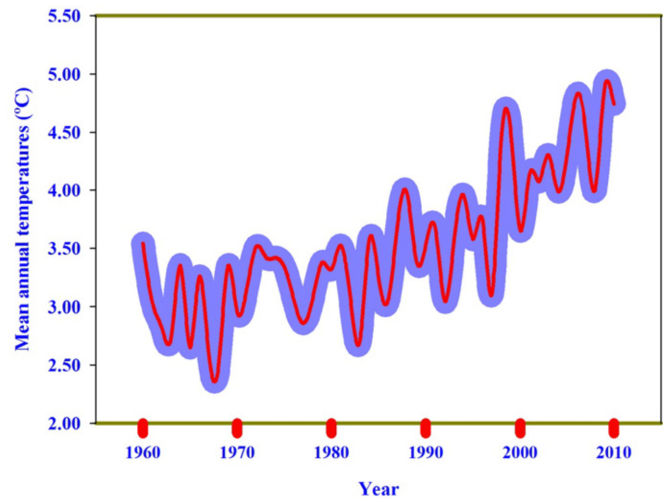

Fig. 1. The change of mean annual temperature on the Qinghai–Tibet Plateau since the 1960s.

high transparency atmosphere, low water and dust content in the atmosphere [47], and annual total radiation amount ranges 4000–9500 MJ/m^2, four peak zones of solar radiation are located in Shigatze Prefecture of Tibetan Autonomous Region, Ari Prefecture of Tibetan autonomous region, the Qaidam Basin, and western Sichuan Plateau, receiving an annual radiation of over 6750 MJ/m^2, respectively (see Fig. 2), and three peak zones of annual sunshine hours are situated in the northern west part of Shigatze Prefecture, northern west part of Ari Prefecture, and northern west part of Qaidam Basin, respectively, receiving an annual 3250–3500 h of sunshine (see Fig. 3). It has been estimated that the QTP has 2.57 million km^2 of areas [29], most of which is located in Zones I (annual solar radiation > 1750 kW h/m^2) and II (annual solar radiation ranges 1400–1750 kW h/m^2) [45]. It is assumed that using1% and 2% of area respectively to install solar photovoltaic systems with the current conservative technology level of 120 kW h/m^2 annual energy generation, and the totally annual power generation would be 3086 TW h and 6174 TW h, equivalent to the power generating capacity of 9259 and 18524 million tce, respectively.

3.3. Positive effect of solar energy utilization on CO_2 abatement

It is well known that greenhouse effect has generally been used for the role of the whole atmosphere in keeping the surface of the earth warm. Recently, however, it has been increasingly associated with the contribution of CO_2, which is estimated to contribute about 50% to the anthropogenic greenhouse effect [48], and it has long been recognized that excessive use of fossil fuels is the main source of CO_2 emission; therefore, renewable promotion of clean energy is eagerly required. Solar energy is one of the cleanest energy resources that does not compromise or add to the global warming, it is often called "alternative energy" to fossil fuel energy sources such as oil and coal [49]. In this section, we look at the potential role for solar energy utilization in offsetting CO_2 emission. But to understand the potential magnitude of this role, suppose solar energy utilizations are currently economically competitive with fossil-fuelled electricity sources. Based on collected data of solar energy exploitation during 2000–2010 in the entire rural areas of China, and literature [35], we can estimate the annual energy conservation and abatement amount of CO_2 by categories of the solar cookers, the solar water heaters, the solar greenhouses, and the photovoltaic system exploitation in rural areas of China from 2000 to 2010, respectively. Results show that annual energy conservation increases from 2.42 million tce in

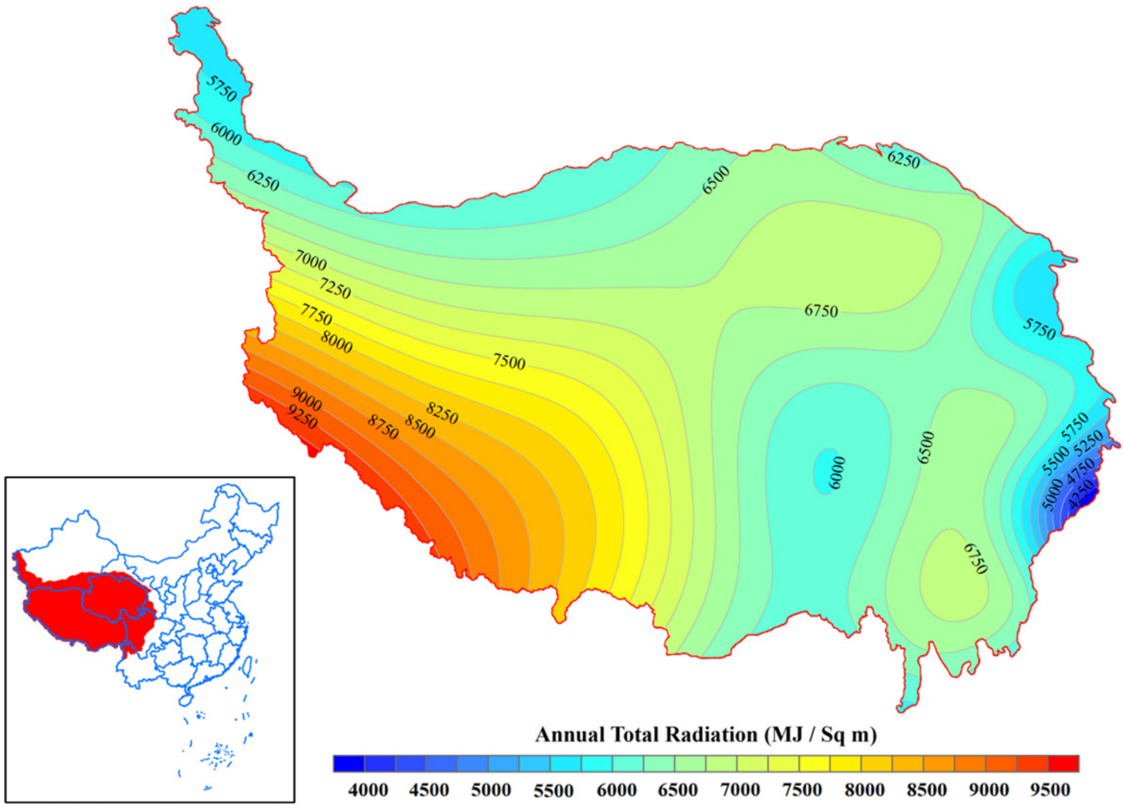

Fig. 2. The spatial distribution of annual total radiation on the Qinghai–Tibet Plateau.

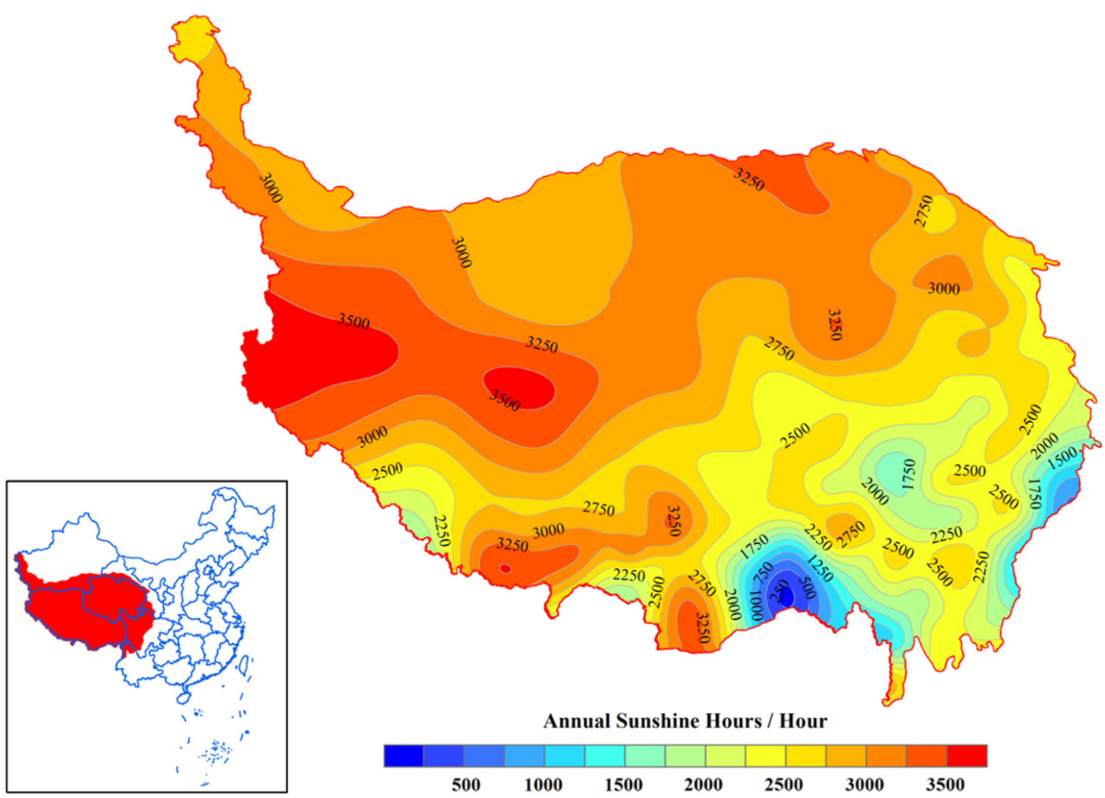

Fig. 3. The spatial distribution of annual sunshine hours on the Qinghai–Tibet Plateau.

2000, to 8.63 million tce in 2010; corresponding to the abatement of CO_2 increases from 5.51 million tons in 2000, to 19.65 million tons in 2010 in the entire rural area of China. Fig. 4 illustrates the dynamic trend of CO_2 abatement with growing share of solar energy utilization in rural energy consumption over time. In order to deepen understanding the structural effect of solar energy

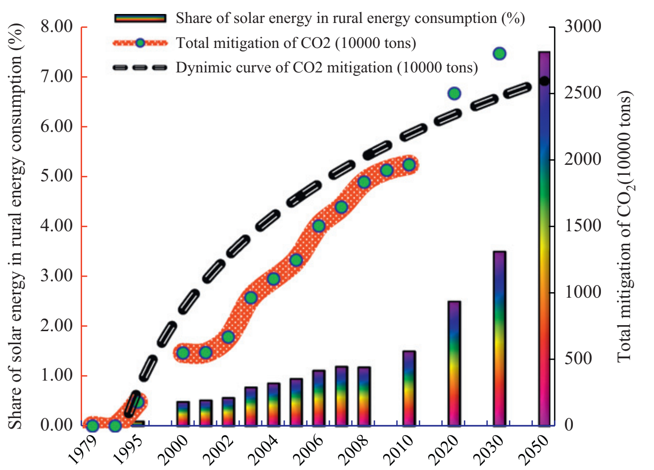

Fig. 4. The effect of solar energy utilization on CO_2 abatement in rural areas of China.

utilization on CO_2 abatement at present in the rural area of China, according to above-estimated data and regression analysis, a conceptual relationship between CO_2 emission reduction and the scale of solar energy exploitation is used to calculate the abatement of CO_2 emission, that is:

$$CO_{2\mathrm{m}} = 171.35 + 1.01SC + 0.34SWH - 0.8SGH + 0.001SPV$$
$$(t\text{-statistics})(1.689) \quad (1.082) \quad (19.70) \quad (-0.64) \quad (0.11) \qquad (1)$$

Sample period: 2000–2010, $R^2 = 0.999$, $F = 1408.68$

where, CO_{2m} is the abatement amount of CO_2 emission, *SC* is the scale of solar cooker exploitation (10,000 units), *SWH* represents the area of solar water heater exploitation (10000 m^2), *SGH* stands for the area of solar greenhouse exploitation (10000 m^2); and *SPV* is the scale of solar photovoltaic systems (Wp), and the estimated Eq. (1) is statistically significant. The elasticity of *SC*, *SWH*, *SGH*, and *SPV* are 1.01%, 0.34%, −0.08%, and 0.001%, respectively. As is shown in Eq. (1), the solar cooker (*SC*) is of most significant contribution to the abatement of CO_2 in the rural area of China, and solar water heater (*SWH*) followed closed behind.

On the QTP, the solar energy utilizations are mainly centralized on the medium and low temperature energy applications. The main applications include the solar cooker, the solar water heater, the solar greenhouse, and the photovoltaic devices in rural household. By the end of 2009, the scales of solar cooker, solar water heater, solar greenhouse exploitation, and installed capacity of solar PV systems reached 923.6 thousand units, 539.4 thousand square meters, 436.3 thousand square meters, and 739.8 kW, respectively. On basis of the Eq. (1), the estimated positive effects of annual energy-saving and CO_2 abatement are 1.27 million tce and 2.90 million tons respectively on the QTP in 2009, which are about 15% of total energy conservation and CO_2 abatement based on solar energy utilization in the entire rural area of China. Although solar energy utilization on the QTP contributes a little to the energy conservation and reduction of CO_2, emission at present plays an important environmental role throughout Asia.

3.4. Growth demand of solar energy utilization on the QTP

As a result of concerns about climate change, many countries worldwide are beginning to establish national goals for the provision of electricity from renewable energy and hence try to set-up the various solar energy policies [49]. China has been working very hard on developing a low carbon economy and utilizing cleaner, renewable resources. Chinese government realize that the solar energy is significant to play an important role in total electrical energy demand, subsequently, the exploitation of solar energy has rapidly developed in recent years and has become a promising source of energy due to its vast reserves, renewable property, near-zero pollutants and GHG emission [50]. From international perspective, environmental preferences and reliability are two competitive benefits of solar water heating system in the international market. It can be said that the use of solar water heating systems can have a great impact on the economic, environmental and energy conservation perspectives [51]. Cooking is the prime requirement for people all over the world, there are number of solar energy based cooking appliances has been design, developed and tested for various applications across the globe [52]. From national perspective, the most extensive utilization is solar water heater, which is broadly utilized to every community in China, especially in remote rural areas of China, and the new total amount of solar water heater in 2005 has a share of 77.3% in the world [46]. Obviously, China has the biggest solar water heater market in the world [53]. Even though the per capita utilization of electricity on the QTP is far lower than the national average, especially in remote mountain areas. However, due to dry climate, thin air, negligible cloud, and annual over 3000 h of sunshine, the QTP is especially suitable for developing solar energy. Therefore, solar water heater and solar cooker area are dominant and widespread solar energy utilization on the QTP (see Fig. 5, Table 1), and the scales of solar cooker, solar water heater, solar greenhouse exploitation have been increasing rapidly with an incredible speed in recent years; the mean growth rates of solar cooker, solar water heater, solar greenhouse, and the PV system exploitation are 32.8%, 6.9%, 0.6% and 0.5% during 2006–2009, respectively, while the average growth rates in the entire rural area of China are 8.1%, 3.5%, 2.4% and 14.7%, respectively, at the corresponding period. Clearly, the exploitation of solar cooker, solar water heater on the QTP indicates a much higher expanded speed when are compared to the average growth rate of the entire rural China.

Table 1 provides general information on rural household with solar energy utilization on the QTP. In comparison, the capacity of solar cooker utilization per rural household on the QTP is about 11 to 24 times more than the average capacity of the rural China; the capacity of solar greenhouse utilization per rural household on the QTP is about 1.3 to 1.7 times more than the average capacity of the rural China, while the developed intensity of solar water heater on the QTP is less than 60% of the rural China at present. However, from a long-term perspective, the solar energy application will occupy bigger share in the energy mix although the scale of solar energy application on the QTP is comparatively small. According to the NDRC (2008) planned target, the annual average growth rate of solar energy utilization will reach 18% during 2010–2020 [54], and according to China's Medium and Long-term Development Plan for Renewable Energy, China's total area of the solar water heater will reach 150 million m^2 by 2010, and 300 million m^2 by 2020. In 2050, the PV generation has a share of 5%, and the capacity of PV generation is 100 GW [46,55]. Furthermore, these initiatives will trigger a huge demand for solar energy application on the QTP in the next future. As shown in Table 1, it is assumed that the capacity of per rural household to use the solar cooker on the QTP increases from 0.22 units in 2009 to 0.50 unities in expected year, and the total scale of the solar cooker utilization would be 2.13 million units, and the capacity of per rural household to use the solar water heater increases from 0.127 m^2 in 2009 to 2.00 m^2 in expected year, and the total area of the solar water heater would be 8.52 million m^2.

3.5. Roadmap of solar energy development on the QTP

It should be noted that solar would be taken as critical low carbon solutions for China's power mix towards the perspectives

Fig. 5. Solar energy utilization of rural household on the Qinghai–Tibet Plateau.

Table 1
The comparison between the entire rural China and the QTP in the capacity of solar energy utilization per rural household.

Items		2000	2005	2010
The mainland of China	Total population (10000 persons)	124,261	130,628	137,053
	Total rural population (10000 persons)	78,384	74,471	67,415
	Total amount of rural household (10000 households)	20,919	23,793	21,747
	Capacity of solar cooker utilization per rural household (units/1000 households)	1.6	2.9	9.0
	Capacity of solar water heater utilization per rural household (m^2/1000 households)	53.1	134.7	229.9
	Capacity of solar greenhouse utilization per rural household (m^2/1000 households)	46.8	63.6	81.6
	Capacity of solar PV system exploitation per rural household (Wp/1000 households)	385.8	401.8	413.9
The QTP	Total population (10000 persons)	1991.5	2,114.5	2283.5
	Total rural population (10000 persons)	1571.6	1,589.6	1657.7
	Total amount of rural household (10000 households)	374.2	397.4	426.1
	Capacity of solar cooker utilization per rural household (units/1000 households)		32.8 (2006)	216.8 (2009)
	Capacity of solar water heater utilization per rural household (m^2/1000 households)		85.6 (2006)	126.6 (2009)
	Capacity of solar greenhouse utilization per rural household (m^2/1000 households)		105.7 (2006)	102.4 (2009)
	Capacity of installed solar PV system per rural household (kW/1000 households)		18.0 (2006)	17.4 (2009)

of 2030 [56]. Previously, in Wang [57], the author has outlined the China roadmap of solar energy technology from 2006 to 2025. In this roadmap, it is divided into four distinct stages, namely, the stage of research on components and system integration (2006–2010), the stage of technology demonstrations and development of production capacity (2011–2015), the stage of construction of commercial solar power plants (2016–2020), and the mature stage of solar energy technology (2021–2025). According to the trajectories, a technology demonstration of solar energy exploitation is the most distinctive feature at present. However, on the QTP, due to the harsh natural environment, even for the same technology, it will be difficult to achieve the technical performance that will be needed in the future unless ongoing technical development is conducted step-by-step. Moreover, considering the abundance of solar resource as well as the cold climate on the QTP, the development pathway of solar energy is different from other regions. Although some technological parameters of solar energy utilization are difficult to quantify, changes in population composition and other socio-economic factors are very complex, a major scenario projection will be needed based on currently available information. In the analysis, quantified target visions were estimated following the dynamical trend, growth requirement of solar exploitation and that of China's Medium and Long-term Development Plan for Renewable Energy (2007), and the Qinghai's Overall Plan of Solar Utilization (2009–2020), the object of solar energy development on the QTP in 2020 contains: Capacity of solar cooker utilization per rural household is 0.35 units, capacity of solar water heater per rural household is 0.20 m^2, capacity of solar greenhouse per rural household is 0.15 m^2. Here, it needs to be stressed that the solar PV industry will enter a rapidly development stage marked by large-scale solar PV planning and construction programme in Qaidam. Accordingly, the capacity of solar PV generating system per rural household will be 2.0 kW, the capacity of PV generating system

Table 2
The future vision and roadmap of rural solar exploitation on the Qinghai–Tibet Plateau.

	2009	2020	2030
Rural household scenarios (10000 households)	426.1	450	480
Target of scale			
Capacity of solar cooker utilization per rural household (units/1000 households)	216.8	350	520
Capacity of solar water heater utilization per rural household (m^2/1000 households)	126.6	200	625
Capacity of solar greenhouse utilization per rural household (m^2/1000 households)	102.4	150	310
Capacity of installed solar PV system per rural household (kW/1000 households)	17.4	2000	4000
Share target of rural solar consumption (%)	1.5 (estimated)	3.0	5.0
Stage of solar energy development	Research and demonstration	Application and promotion	Industrialization and commercialization
Priority regional setting	The source regions of the Yangtze, Yellow, and Lanchang Rivers	Ari Prefecture, Changdu Prefecture, Shigatze Prefecture, Qaidam basin	Qaidam basin, Ari Prefecture, Shigatze Prefecture

will be more than 10 GW (Table 2) in 2020. In 2030, the solar energy has a share of 5% in the whole rural energy supply; the capacity of PV generation system will reach 20 GW; and then Qaidam basin will become the biggest PV power base in China.

As the source regions of the Yangtze, Yellow and Lanchang Rivers is an important supply of fresh water resources in China. It is also an ecological security shelter for the Qinghai–Tibetan Plateau and is of a special importance in the maintenance ecological security and sustainable development for China and southeast Asia. For this reason, in regional distribution of rural solar development, the source regions of the Yangtze, Yellow and Lanchang Rivers should be taken as the top priority area owing to the great environmental and economic benefits by using the solar energy. To provide heat in winter even in summer is the domain needs for rural households on the QTP. As mentioned in Section 3.2, there are the abundant solar resources in the Qaidam Basin, Shigatze Prefecture, and Ari Prefecture. Simultaneously, there is a relative high level of social acceptance and public awareness of solar water heater, solar cooker, and PV system. Therefore, the development of solar energy in these regions is rapid in the recent decades. With the improvement of technology and the decreasing cost of solar utilization, the large-scale grid-connect PV generation is considered by central government and local governments. Specially, based on the planning and construction report of million-kilowatt PV power programme in the Qaidam Basin [58], the total yield of the Qaidam Basin PV will be 1000 MW in 2015, and annual generation of about 1.7 billion kW h in 2020. By 2030, solar power can be easily installed in most of rural households, places that may not be targeted for grid connection for many years, and the stage of solar industrialization and commercialization in most of remote and rural areas will be established on the QTP.

3.6. *Adaptation instruments of solar energy exploitation*

The United Nationals Framework Convention on Climate Change (UNFCCC) highlights the great concern for potential adverse effects of climate change. Hence the inclusion of climatic risks or adverse effects in the design and implementation of national or regional development initiatives is vital to reduce risks, mitigate vulnerability, and enhance sustainability. Adaptation is widely recognized as a necessary means to cope with climatic change impacts, and adaptation needs vary across geographical scales (local, national, regional, global), temporal scales (coping with current impacts versus preparing for long-term change) [30]. Climate change adaption measures are required to increase the resilience of the energy sector at both the large-scale and household levels to future climate conditions. As China moves towards the identification of climate change mitigation and adaptation strategies, China's adaptation strategy of climate change remains centered on the energy development. Thus, the exploitation and utilization of renewable energy, especially solar energy, is a clear domain for climate change adaptation. From a social science perspective, it becomes very critical to understand the conditions under which policies and institutions can stimulate the adaptive capacity of society to deal with the potentially serious and irreversible impacts of climate change [59]. With regard to solar-related regulations at different scales, we noted that formal policies and regulatory instruments have been in place in China for many years. The National People's Congress adopted the Renewable Energy Law of the People's Republic of China (RELPRC), which was officially enacted in 2005. The RELPRC provides basic principles developing and governing renewable energy. In addition, based on different scales, many crucial activities of solar energy exploitation in rural areas of China have been formally implemented by Chinese central government, Qinghai and Tibet local governments since the 1990s (see Table 3). From national scale, effective initiatives, such qas "Brightness Programme", "Chinese Township Electrification Programme", "Med- and Long-Term Development Plan for Renewable Energy in China", "Chinese Village Electrification Programme", and "Golden Sun Programme", the "12th Five-Year Plan for the Solar Industry Development" etc., appear to have increased since 1999. From regional scale, main activities and instruments of adaptation listed in Table 3 include "Sunlight Plan in Tibet", "Light of Science Plan in Tibet Autonomous Region", "Industrial Development in Qinghai Province and Promote the Use of Solar Energy Plan", "The 12th Five-Year (2005–2010) Plan for Economic and Social Development of Tibet Autonomous Region", and "The 12th Five-Year Plan for Economic and Social Development of Qinghai Province" etc. Clearly, from the early planning phase, solar energy project was designed to expand into vast rural areas of the QTP; these initiatives and activities were instrumental in enhancing the adaptive capacity not only from regional scale but from enterprise or individual scale. Meanwhile, it is important to mention here that Chinese government formulated the China National Plan for Coping with Climate Change (CNPCCC) in June 2007, the focus on three main objectives related to solar energy (e.g., quantifying the indicator of CO_2 abatement by energy conservation, renewable energy development, and structural optimizing of energy consumption; identifying the key supporting policies; and formulating the implementation mechanism of renewable energy development) can be found in the CNPCCC. In 2011, the Chinese government released the Comprehensive Work Plan for Energy Conservation and Emission Reduction during the 12th Five-Year Plan and the Work Plan for Greenhouse

Table 3
Solar-related policy and regulatory instruments of climate adaptation in rural areas.

Scales	Policies and actions	Solar-related description
International	The Millennium Development Goals (MDGs) (2000)	The linking of MDGs to energy services in rural areas is now being looked at carefully by many; Many international development agencies (such as DFID, UN, GVEP, REEP, ACP-EU etc.)have noted how energy can play a crucial role in underpinning efforts to achieve the MDGs.
	China Rural Energy Enterprise Development Initiative (CREED) (2004–2006)	Offering energy services to western rural customers of China based on energy technologies and practices that are environmentally more sustainable than current approaches. The total overall budget of CREED project was 12.311 million US$, with support from the United Nations Foundation.
	China Renewable Energy Scale-up Programme (CRESP) (2005)	This program is along with the World Bank and Global Environment Facility. The goal of the program is armed to demonstrate the feasibility of scale-up renewable technologies and their economic and environmental advantages over coal-fired energy generation.
	Solar Energy Training and Service Project in Tibet (2004–2006)	Based on Sino-Italian Energy and Environmental Cooperation, besides a solar energy demonstration village in Inner Mongolia, a biomass project in Ningxia, and an energy efficient building in Tsinghua University, the solar energy training center in Tibet is the most important part of this project, this center is to build 5 kW PV stand-alone plant, to establish demonstration PV plants, and to compile English teaching manual of training lessons on designing, installing, and maintaining of PV plants.
	Asia Solar Energy Initiative (ASEI) (2010)	Announced by the Asia Development Bank (ADB) in May 2010, the overall objective of the ASEI is to create a virtuous cycle of solar investments in Asia and the Pacific toward achieving grid parity by helping developing member countries realize the fruits of a clean, renewable source of energy.
National	Brightness Programme (1999–2002)	The plan relied on solar and wind applications to provide electricity to 23 million people located in Gansu, Qinghai, Inner Mongolia, Tibet and Xingjian by 2010, and to provide 100 W of capacity per person.
	Chinese Township Electrification Programme (SDDX) (2002–2005)	Meeting the power needs of public utilities and residents of un-electrified township in remote areas, border regions of western China. The total investment for the programme is 4.7 billion RMB.
	The Renewable Energy Law of the People's Republic of China (2005)	Giving priority to renewable energy when transmitted on the state power grid, purchasing renewable energy at full price, giving users of renewable energy price discounts and sharing the utilization of renewable energy among the whole society.
	The 11th Five Year Plan for the Solar Industry Development (2006–2010)	Actively developing small-scale PV power plants to solve the power shortage problem in remote places such as Tibet, Qinghai, Xinjiang and Inner Mongolia. Similarly, China will build on-grid large-scale PV power plants in those places that have rich solar PV power resources, such as Tibet, Gansu, Inner Mongolia, Ningxia, and Xinjiang.
	China's National Climate Change Program (2007)	Optimizing energy mix and improve energy efficiency; actively developing solar power and solar heating, including popularizing family-use photovoltaic power system; and popularizing household solar water heater, solar greenhouse and solar stove in rural areas.
	Med- and long-term development plan for renewable energy in China (2007)	Actively taking advantage of solar power to generate electricity and using it for heating while strengthening the research, development of new energy and alternative energy. By 2010, the total capacity of solar power in China will be 300 MW, by 2020, it will be 1.8 GW.
	China National Plan for Coping with Climate Change (2007)	Strengthening policy guidance energy conservation and efficient utilization; optimizing the energy consumption structure through rapidly developing renewable energy, especially solar energy.
	Chinese Village Electrification Programme (2006–2010)	Providing renewable electricity to 3.5 million households in 10000 villages by 2010. This is to be followed by full rural electrification using renewable energy (solar energy is expected to play a major role) by 2015 in China's off-grid western region.
	Golden Sun Programme (2009–2011)	Supporting the installation of solar photovoltaic applications. Despite the program is designed to subsidize the total cost of both on-grid and off-grid applications, the focus on the latter is clear with the offer of 70% upfront subsidies for these systems in rural areas.
	The 12th Five Year Plan for the Solar Industry Development (2011–2015)	According to the plan, China will reduce the cost of solar power to 0.8 yuan (12 US cents) per kilowatt-hour by 2015 and 0.6 yuan per kWh by 2020. Chinese government will also help companies in the solar sector increase annual sales. It aims to have at least one company reaching 100 billion yuan in sales by 2015, and between three and five companies reaching 50 billion yuan by the same date. At the same time, China will put more effort into the production technology for building integrated PV in the coming years.
Regional	Sunlight Plan in Tibet (1990–)	With the support of Solar Energy Research Institute and the German Embassy, currently half a million Tibet residents, or 17.2% of the population use solar energy for cooking and heating.
	Light of Science Plan in Tibet Autonomous Region (1999–2001)	Implementation household-based PV systems, solar cooker, solar power system in Ari, Changdu, Shigatze. The total investment is 3 million RMB, 50000 farmers and herdsmen benefit from this programme.
	Industrial Development in Qinghai Province and Promote the Use of Solar Energy Plan (2009–2015)	Promoting use of solar energy, development and utilization of solar PV lighting, solar water heating systems, solar heating systems, passive solar houses, solar cookers. By 2015, the total capacity of installed solar power will be 1 GW; the share of solar energy will reach 5% of total energy consumption in Qinghai; By 2020, the total capacity of installed solar power will reach 10 GW; and 20 GW in 2030.
	The 12th Five-Year Plan for Economic and Social Development of Tibet Autonomous Region (2011–2015)	Actively development of solar power, and establishment the national base for solar energy research, solar energy utilization and demonstration. By the end of 2015, the total installed capacity of solar power will reach 160 MW.
	The 12th Five-Year Plan for Economic and Social Development of Qinghai Province (2011–2015)	Accelerating the development of 20 GW solar power project in Qaidam basin, making Qaidam basin the biggest PV power base in China, and implementation the strategy of "Solar City" construction in Golmud, gradually construction of Golmud photovoltaic industrial park.
Enterprise	10 MW solar PV project in Shigatze and 50 MW PV project in Nagqu (2010)	10 MW solar PV project invested by Longyuan Power Group in Shigatze, the plant should generate 430 million kWh of electricity during its 25-year life span. Also, Longyuan Group signed a strategic cooperation agreement with the Administrative Office of the Nagqu Prefecture, Longyuan Group will complete the construction of 50 MW PV project by 2015.
	The development of Qaidam Basin-based solar photovoltaic industry(2010-)	So far, 26 companies (for example China' Guodian, Huaneng Power International Inc., Qinghai Hydropower Group, Golmud PV Power Generation Company, Longyuan Golmud New Energy Development Company etc.) have submitted plans of building solar power plants in Golmud to the provincial development and reform commission, the total installed capacity of the 26 companies' plants in the city exceeds 3500 MW.

Note: DFID: the UK's Department for International Development; UN: the United Nations; GVEP: the Global Village Energy Partnership; REEEP: the Renewable Energy and Energy Efficiency Partnership; ACP-EU: Africa Caribbean Pacific-European Union. SDDX: the Song Dian Dao Xiang, literally "Sending Electricity to Townships". ADB: the Asia Development Bank.

Gas Emission Control during the 12th Five-Year Plan period. Indeed, activation of these plans represented a turning point and created a new era for solar energy development on the QTP.

In turn, if the cost of solar energy is too expensive for rural household who need it, then the issue of subsidies or grants cannot be avoided [60]. No doubt subsidies, which are provided by the central and local governments, are one of the most popular economic incentives for increasing solar energy for rural areas [60]. For instance, in late 2001, China launched an ambitious renewable energy-based rural electrification programme known as Song Dian Dao Xiang (SDDX), literally “Sending Electricity to Townships.” The government provided US$ 240 million or RMB 2 billion, to subsidize the capital cost of equipment [60], of which, Tibet and Qinghai with 40%, 13.3% investment occupied, respectively (see Table 4). It has enough critical mass to create a truly robust and sustainable solar energy infrastructure in rural area of China, especially for PV. Therefore, embedding climate change adaptation into sector policies (solar-related policies, financial mechanisms), programmes (solar-related projects), and development planning (solar-related exploitation planning), expands the range of opportunities for reducing vulnerability and also enables impacts to be addressed in a more economically efficient manner [61].

Despite excellent achievements achieved in solar energy development, many practical issues exist such as high cost and lack of market competitiveness due to the technical problems of solar energy exploitation [62]. High cost is the main factor that restricts scale development of solar power [63]. Empirical evidence shows that the overall solar energy supply and use system is scant. Overall planning and investment in the rural solar energy continue to lag behind those efforts in urbanized regions [64]. In a broader analysis, many researchers such as Ling et al. [65], Xiao et al. [66], Qu et al. [67], Zhang et al. [68], Wang and Qiu [47], Liu et al. [46], Rigter and Vidican [69], Zhao et al. [70], Liu et al. [45] pointed out that the high price of raw materials and electricity, small scale markets, lack of product and technology standards and instable quality are constraining the sustainable development of China's solar energy. On the other hand, Zhang and Kumar further confirmed that lack of subsidy has led to a series of problems like the loss of operator and failure to update the system components [71]. The village power systems installed before 2006 are therefore facing the situation of possible malfunction. It is a kind of policy limitation that the household system cannot share this subsidy. It is worth noting, however, for the QTP, the vast majorities of 16.58 million people in rural household are still dependent on the traditional fuels for cooking and lighting such as wood, dung and crop residues. In addition to overall poverty in rural areas, low density of demand and remoteness of location, raises the cost and reduces profitability of solar energy supplies to scatted farmers and herdsmen of the QTP. To make a significant contribution to the problem of climate change adaptation, an accelerated adoption of solar energy technologies is requirement. The speed of transition from fossil fuel combustion to a portfolio of low carbon technologies is constrained by manufacturing capacity and ultimately cost. Obviously, technology and cost are two major barriers to the development of solar energy in rural area of China. During the process of solar energy exploitation, the government plays a role as coordinator and motivator [67,70]. With this mind, the development of solar energy still requires a series of preferential and robust policies from the government, such as cogent financial subsidies, tax concessions, favorable price policy, technical innovation policy, industrialized support policy, and effective globe cooperation and collaboration framework [47,62,66,68,72–74]. At the same time, the application of cross-subsidy as a necessary means to fill the gap between the revenues and costs associated with power systems deserves special attention [71].

In addition, another important aspect associated with solar exploitations is the knowledge training for farmers and herdsmen on the QTP. Because of Tibetans' refuse to accepted free solar cookers presented by the government in the past since they took sun for a god, who should not serve human beings. Even though training on science and technology knowledge in recent years on the QTP has made locals more knowledgeable about the sun and solar energy. Solar energy (especially solar cooker, solar water heater etc.) has been accepted by the majority of local farmers and herdsmen. However, the lack of technical know-how and follow-up, acceptance of local people obstructs the utilization of solar energy, the training of local technicians, environmental awareness for management and maintenance of solar equipment make sense in expanding the use of solar cooker and solar water heater [47,31]. Similarly, there is scientific agreement that the social acceptance of local residents to the renewable energy technologies is influential not only to the renewable energy project itself but also to the success of sustainable development of the region [75]. Therefore, future priorities of policy should still include the awareness training for farmers and herdsmen in solar energy [72]. Residents' education and training plays a key role in the level of awareness of solar energy technologies and decision to implement these technologies at home [76].

Table 4
Preliminary SDDX installation information by the QTP-related provinces.

Provinces/ autonomous regions	Number of townships	Installed capacity (kW)	Total investment (CNY million)	NDRC grant (%)	Provincial grant (%)
Tibet	350	6,700	800	100	0
Qinghai	86	2,600	266	80	20
Sichuan	51	1,600	180	50	50
Gansu	12	1,230	113	50	50
Xingjian	48	1,932.45	177	50	50
Total	547	14,062.45	1536		

NDRC: National Development and Reform Commission, Source: the United Nations Industrial Development Organization (UNIDO), Renewable Energy & Energy Efficiency Partnership (REEEP). 2005. Sustainable Energy Regulation and Policymaking for Africa(training package)-Module 10: Increasing access to energy services in rural areas.P44.http://afric-toolkit.reeep.org/module/Module10.pdf.

4. Conclusions

In response to climate change, households may alter fuel choice and the quantity of fuel. Due to the abundance of solar resource on the QTP, household-based energy consumption is of great significance for CO_2 emission, which could be mitigated through enhancing the utilization of solar energy.

The most effective adaptation method with which to increase solar energy services in rural areas of QTP is the policy instrument. Adaptation measures of solar energy exploitation could significantly decrease the risks of climate change for the QTP. Investments and training in such implementation efforts would undoubtedly pay high dividends in advancing smoothly development of solar energy for rural household.

It is essential that a gradual transition to solar energy systems must be achieved if poverty alleviation and sustainability is to be realized in rural areas of the QTP.

Acknowledgements

This work was supported by a research grant from the National Basic Research Program of China (Grant No. 2010CB 951704).

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